A Study on Phase Angle Deviation During Thermomechanical Fatigue of Hastelloy X

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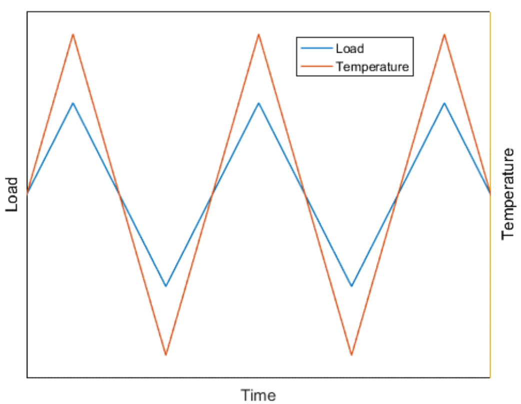
Definitions

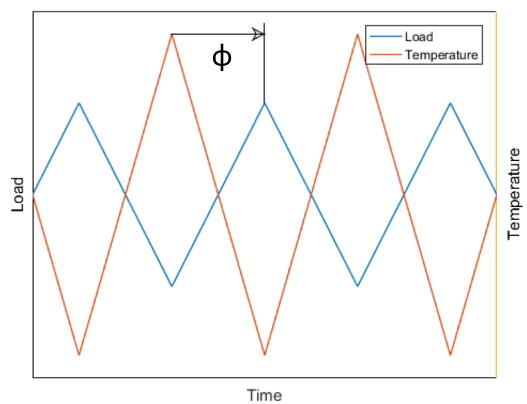
Temperature \ Load		Constant: P = 0	Constant: P ≠ 0	Cyclic
Constant	T = RT	No Loads	Mechanical Strain	Mechanical Fatigue
	T > RT	Free Thermal Expansion	Creep	Isothermal Fatigue
Cyclic		Thermal Fatigue	Thermal Fatigue Influenced by Creep	Thermo-mechanical Fatigue

- Thermo-mechanical Fatigue (TMF): cycling of both temperature and load
- Phase(ϕ): relative offset between temperature and load
- In-Phase (IP) TMF: peak load reached at peak temperature, ϕ= 0°
- Out-of-Phase (OP) TMF: peak load reached at lowest temperature, ϕ = 180 °
- Alternative-Phase (AP) TMF: offset between peak load and peak temperature, ϕ ≠ 180°, 0°

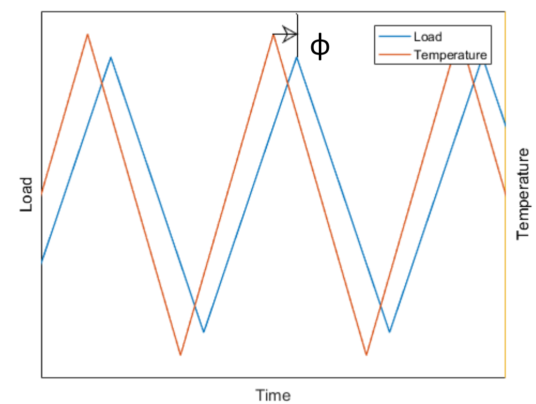
IP TMF



OP TMF

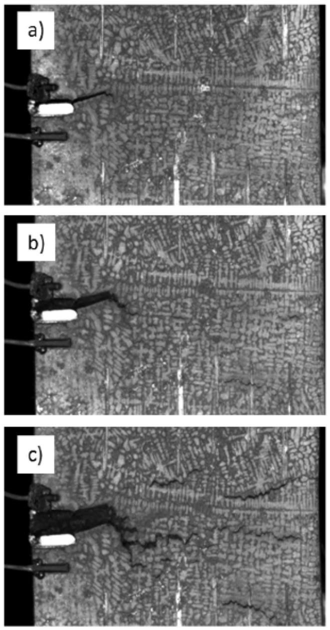


AP TMF



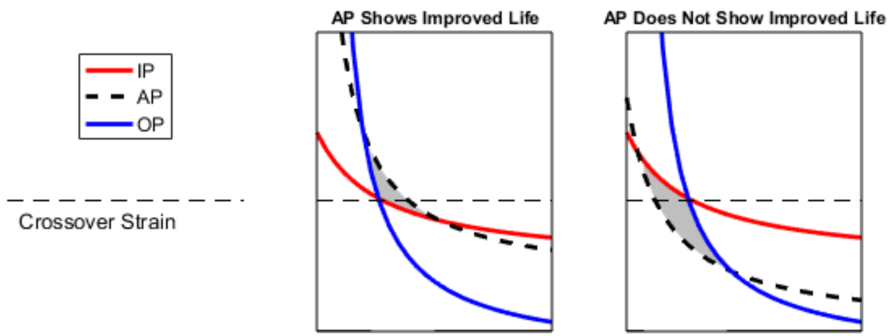
Background

During TMF materials are damaged by creep, oxidation, and fatigue

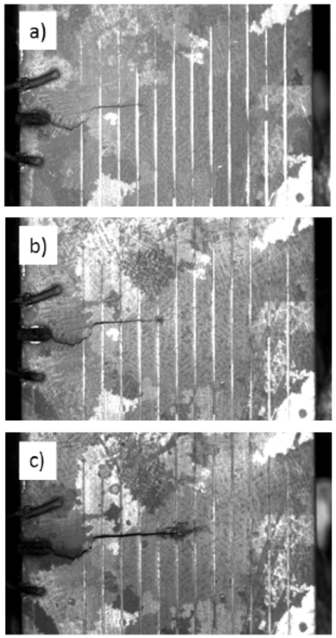


IP TMF is driven by creep

[2]



OP TMF is driven by oxidation

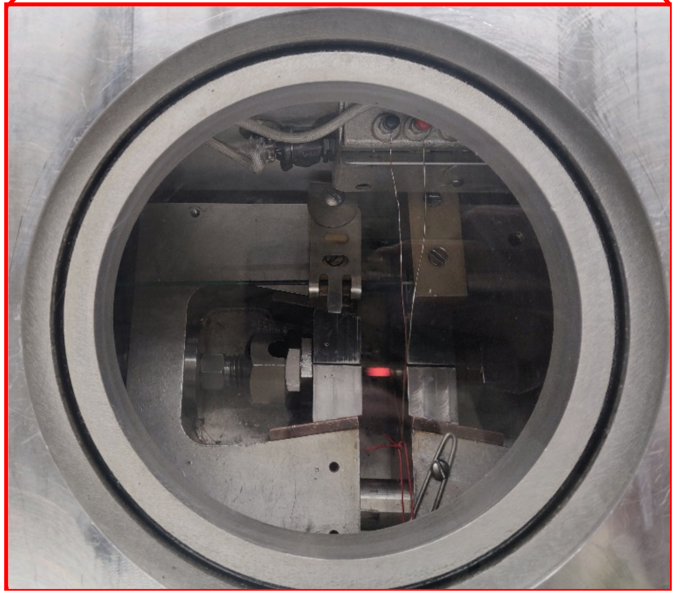


[2]

- At higher strains OP shows better fatigue life
- At a specific strain IP begins to show better fatigue life
- This called a crossover strain
- **We are testing to see if AP can show improved fatigue life**
  - We believe it will exist at the crossover strain

[2] S. Eckmann, and C. Schweizer, Characterization of fatigue crack growth, damage mechanisms and damage evolution of the nickel-based superalloys MAR-M247 CC (HIP) and CM-247 LC under thermomechanical fatigue loading using in situ optical microscopy, Int J Fatigue, Vol. 99, Part 2, (2017).

Experimental Setup

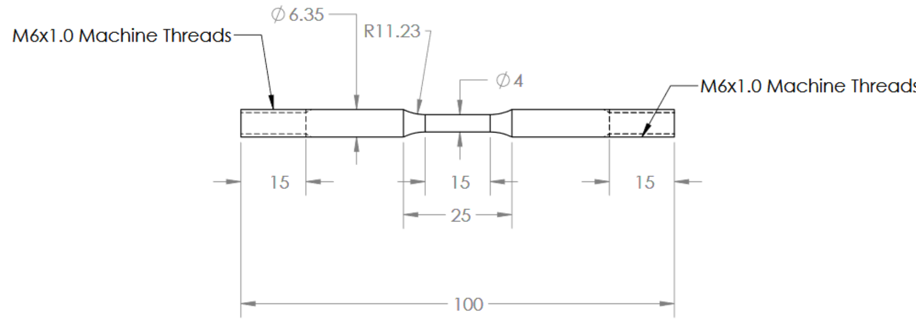


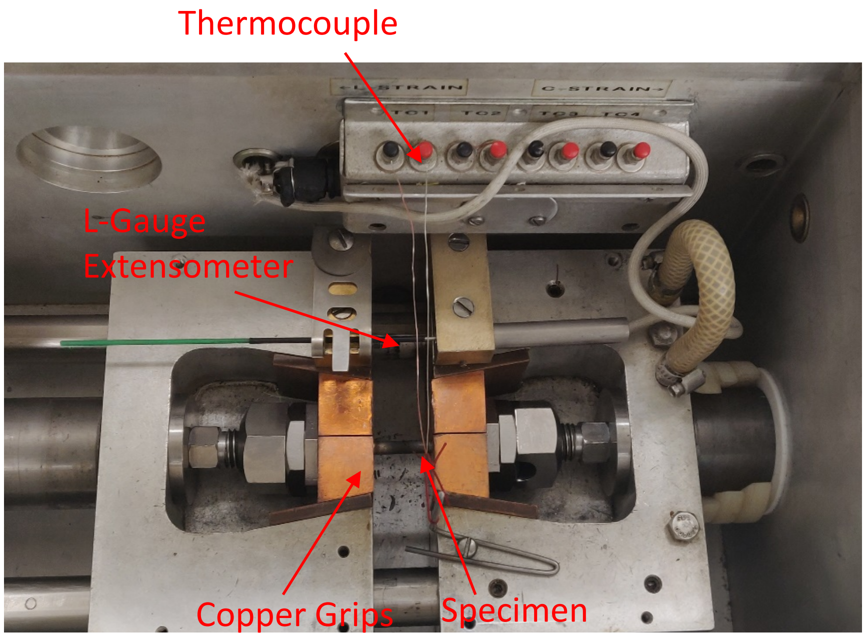
Tests performed using a Gleeble 1500D Thermomechanical simulator:

- 50 kN Load Cell
- Resistive joule heater
- Environmental chamber capable of high vacuum

Specimen Design

- Specimens are a made out of Hastelloy X, a high temperature nickel superalloy
    - High temperature strength
    - Oxidation resistance
    - Used in nuclear and other high temperature applications
- Machined out of ¼" rod



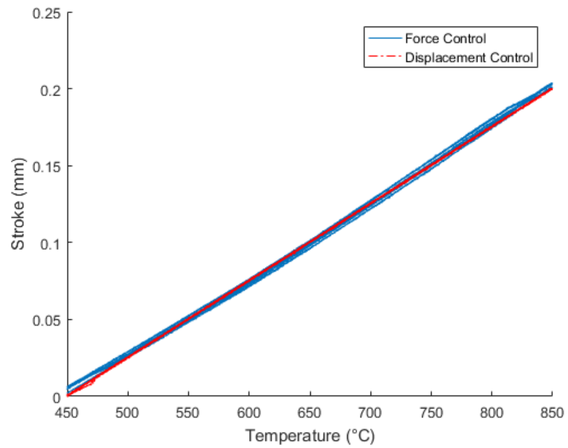


TMF Code-of-Practice

- A European Commission funded collaboration of over 20 countries
- Aims to standardize TMF testing
- It covers:
  - Testing apparatus
  - Specimen design
  - Pretesting procedure
  - Test execution
  - Proper reporting

Pre-test Procedure

Thermal Strain Compensation

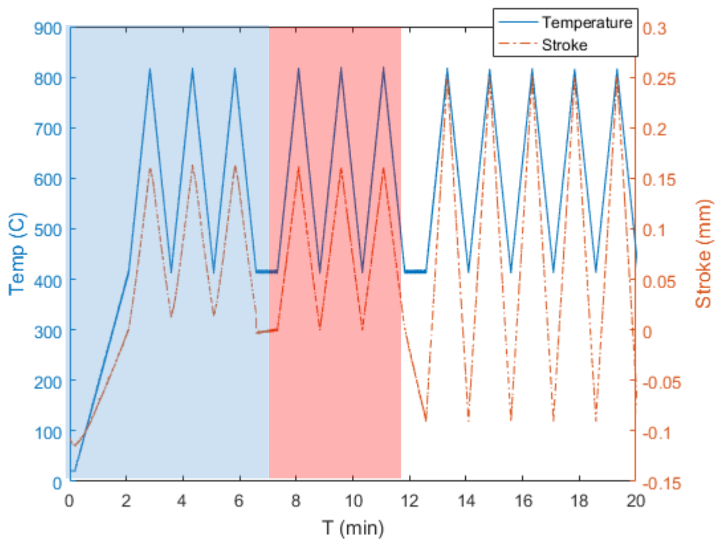


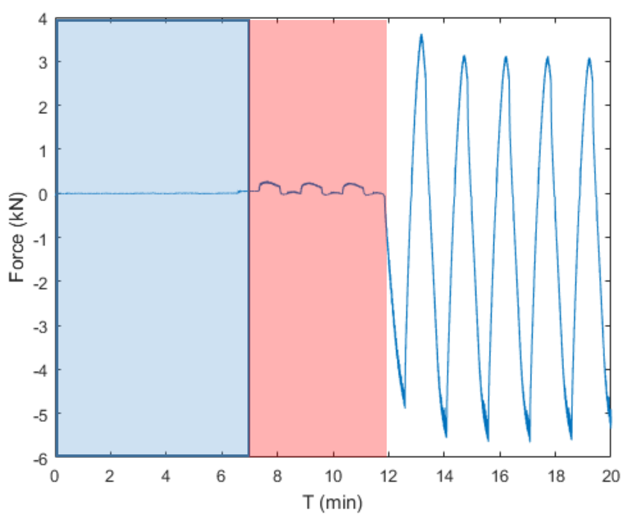
- Temperatures cycle between 450 °C and 850 °C
- Heating rate of 10 °C/s
- 1.5 min/cycle

Force Control

Displacement Control

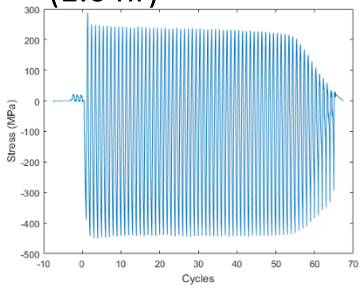
Before each session



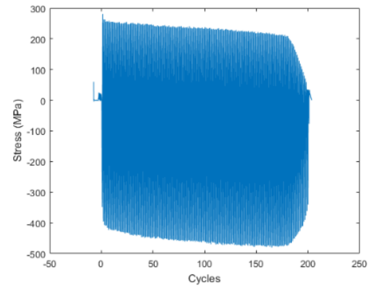


Testing

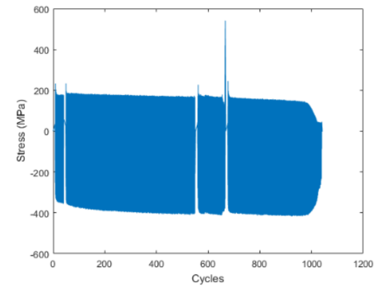
IP ε = 0.9%: 65 cycles to failure (1.6 hr)



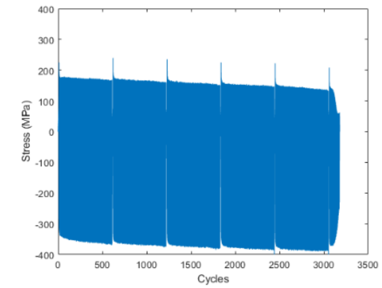
IP ε = 0.6%: 203 cycles to failure (5hr)



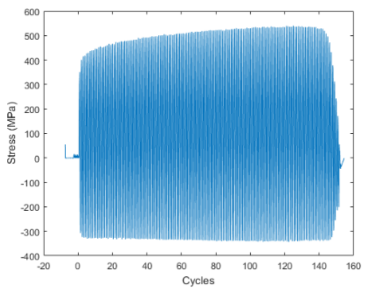
IP ε = 0.4%: 1011 cycles to failure (25.3 hr)



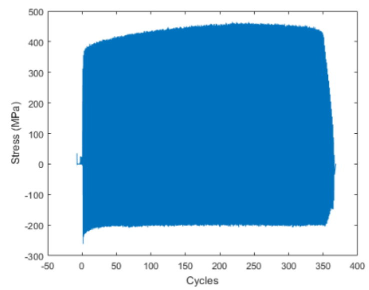
IP ε = 0.3%: 3178 cycles to failure (79.9 hr)



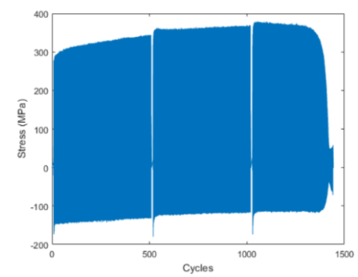
OP ε = 0.9%: 203 cycles to failure (5 hr)



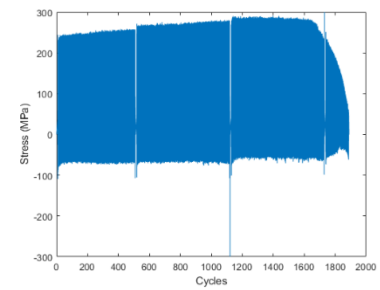
OP ε = 0.6%: 368 cycles to failure (9.2 hr)



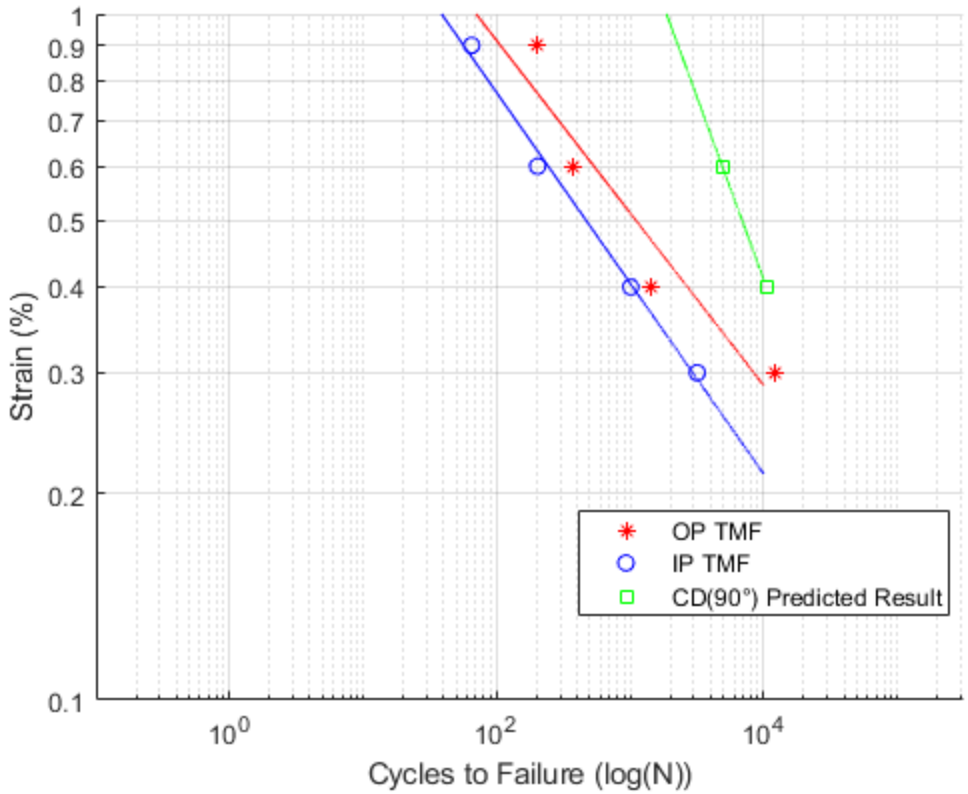
OP ε = 0.4%: 1443 cycles to failure (36hr)



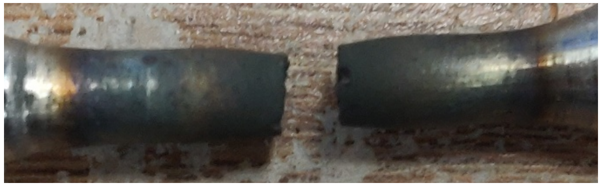
OP ε = 0.3%: 1889 cycles to failure (47 hr)



Preliminary Results

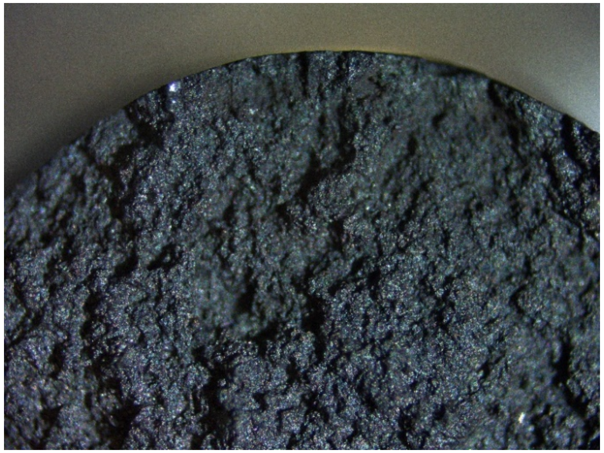


Failed IP Specimen



Failed OP Specimen

IP Fracture Surface

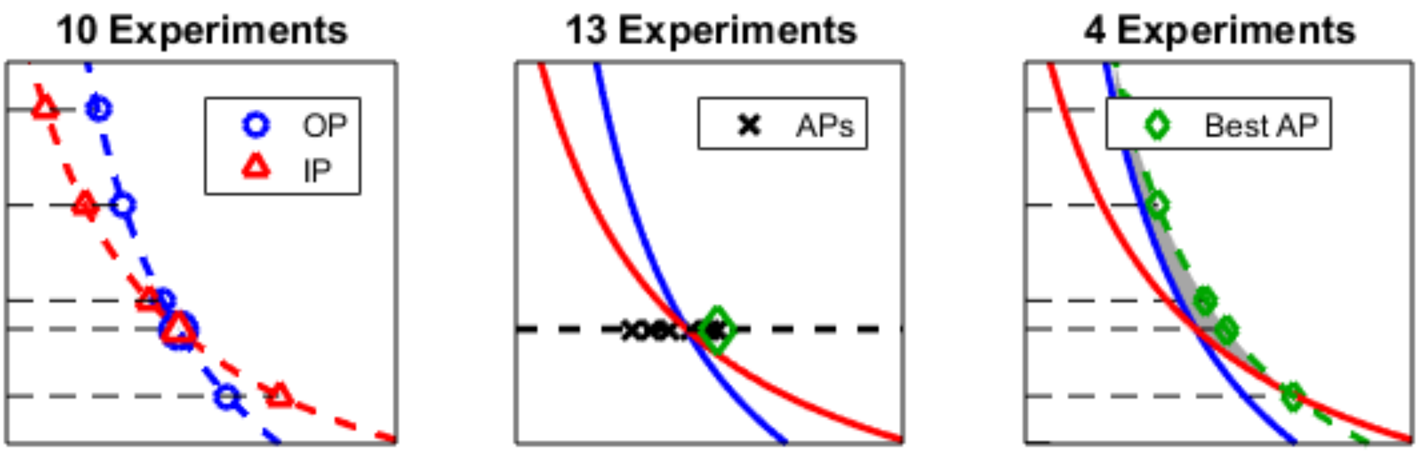


Next Steps

We are going to develop an AP S-N Curve

Original plan:

- Find crossover strain of Hastelloy X
- Test different a range of AP's at that crossover strain
- Develop a new S-N curve for the best AP



Due to the high testing time:

- Use the completed IP and OP tests as a baseline
- Test differing phase angles at higher strains (much shorter testing time)
- Develop a new S-N curve for the best AP

Acknowledgements

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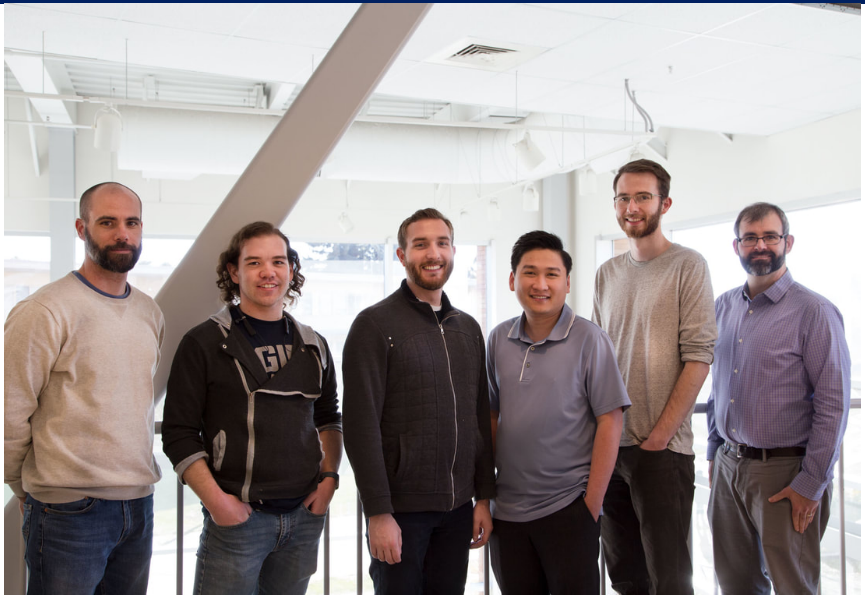

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